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RESEARCH MEMORANDUM

A PRELIMINARY INVESTIGATION OF THE PERFORMANCE OF A

SHORT-LENGTH TURBOJET COMBUSTOR USING

VAPORIZED HYDROCARBON FUELS

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NATIONAL ADVISORY COMMITTEE
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A PRELIMINARY INVESTIGATION OF THE PERFORMANCE OF A SHORT-LENGTH

TURBOJET COMBUSTOR USING VAPORIZED HYDROCARBON FUELS

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SUMMARY

Two short turbojet combustors designed for use with vaporized hydro-
carbon fuels were tested in a one-quarter annular duct. The experimental
combustors consisted of many small "swirl-can" combustor elements mani-
folded together. This design approach allowed the secondary mixing zone
to be considerably reduced over that of conventional combustors. The
over-all combustion lengths, for the two configurations were 13.5 and 11.0
inches, approximately one-half the length of the shortest conventional
combustors.

These short combustors did not provide combustion efficiencies as
high as those for conventional combustors at low pressures. However,
over the range of combustor-inlet total-pressures expected in aircraft
capable of flight at Mach numbers of 2.5 and above, these short combus-
tors gave very high efficiencies. A combustion efficiency of 97 percent
was obtained at a combustor-inlet total-pressure of 25.0 inches of mercury
absolute, reference velocity of 120 feet per second, and inlet-air total
temperature of 1160° R. By proportioning the fuel flow between the mani-
fold rows of can combustor elements, control of the combustor-outlet
radial total-temperature profile was demonstrated. Combustor total-
pressure loss varied from 0.75 percent of the inlet total pressure at
isothermal conditions and a reference velocity of 75 feet per second to
5.5 percent at a total-temperature ratio of 1.8 and a reference velocity
of 180 feet per second.

INTRODUCTION

Turbojet engines are being used to propel aircraft at progressively
higher flight Mach numbers; thus, higher combustor inlet temperatures,
higher reference velocities, and generally higher pressures in the com-
bustors result. In addition, advances in compressor and turbine design
provide higher airflow rates per unit frontal area; still further in-
creases in combustor reference velocity are required if the combustor is
to remain within the engine envelope fixed by the rotating components.
In the combustors for high flight Mach numbers described in references 1
to 3, the pressure losses, because of the high reference velocities, are
higher than for conventional combustors for subsonic flight. A reduction
in pressure loss for these combustors is therefore desirable.

Another important objective for combustors designed for high flight Mach numbers is a reduction in combustor length. The combustors of references 1 to 3 have lengths comparable to those of conventional combustors for subsonic flight. Insofar as the burning process is concerned, it would appear possible to reduce the length of combustors designed for high flight Mach numbers, because the high pressures and inlet temperatures are favorable for burning. However, attempts to reduce the pressure loss and length of combustors such as those of references 1 to 3 seriously impair the combustor outlet temperature profile.

A new design approach that appears promising for reducing both the length and the pressure losses, stems from a consideration of the basic combustion processes. This approach involves combining the location and the sequence of such operations as fuel introduction, mixing of the fuel and air, flame stabilization, combustion, and dilution of hot gases. Such combination may provide adequate performance and also permit considerable savings in combustor length and, consequently, in over-all engine length and weight.

In following this design approach, small combustor elements were substituted for the single large combustor used in present-day turbojet engines. In these small combustors, fuel is injected, mixed with a small amount of air, and the flame stabilized within the combustor. Secondary air flows around and between the combustors, completing the combustion process and diluting the hot exhaust gases. This type of combustor gives many small jets of high-temperature combustion products rather than the single large core of high-temperature gas produced by conventional combustors; the mixing length and the pressure losses required to arrive at the desired turbine-inlet temperature profile are thereby greatly reduced.

Another advantage of this type of combustor design is the ease with which it may be adapted to various combustor sizes simply by changing the number of combustor elements. Furthermore, the use of different-size combustor elements should give added flexibility.

The research program described herein was intended as a preliminary study of the feasibility of two short turbojet combustors designed according to the principles just outlined. The two test combustors were constructed by manifolding many small swirl-can combustor elements (10 in one case and 20 in the other). These elements were small tapered cans about 2 inches long and had an exit diameter of about 2 inches. Vapor fuel, either propane or prevaporized JP-4 grade fuel, was introduced into these swirl cans tangential to the inner surface at sonic velocity.

The test combustors were mounted in the housing of a one-quarter sector of an annular turbojet combustor. Combustion efficiencies and total-pressure losses were determined over a range of inlet total pressures from approximately 0.5 to 1.0 atmosphere, reference velocities from 75 to 180 feet per second, and inlet total temperatures from 810° to 1160° R. Provisions were made to control the combustor-outlet temperature profile, and examples showing this control are presented.

SYMBOLS

The following symbols are used in this report:

f fuel-air ratio

P total pressure, in. Hg abs

P_i combustion-inlet total pressure, in. Hg abs

T_i combustion-inlet total temperature, $^{\circ}R$

T_o combustion-outlet total temperature, $^{\circ}R$

V_{ref} reference velocity, ft/sec

V_{ref}/P_iT_i combustion parameter

η_c combustion efficiency

APPARATUS AND PROCEDURE

Installation

A schematic diagram of the combustor installation is shown in figure 1. Air of the desired quantity and pressure was drawn from the laboratory system, metered with a sharp-edged orifice, heated to the desired temperature in the heat exchanger, and then passed through the test combustor and into the laboratory exhaust system. Airflow rates and combustor pressures were controlled by the airflow and altitude exhaust valves, respectively.

The fuel system used for propane operation is shown in figure 2. Gaseous propane was drawn from the top of the storage bottle, reduced to the desired pressure, metered with a sharp-edged orifice, and passed into the test combustor. A provision was made to divide the flow of propane gas into three separate streams for use with model 2, described in Combustors.

Liquid JP-4 fuel was drawn from the laboratory supply system, pumped through a rotameter, and into a fuel vaporizer installed in the duct downstream of the combustor. Here the JP-4 fuel was vaporized and piped outside the combustor in insulated tubes to the external fuel manifold.

The combustor test section consisted of a one-quarter sector of an annular combustor having an outside diameter of 25.5 inches and an internal diameter of 10.8 inches. The combustor cross-sectional area was approximately 104.5 square inches. The swirl-can combustors were entirely

supported by 3/8 inch bulkhead fittings through which the fuel was fed
to the combustor. Ignition was provided by a sparkplug with an extended
center electrode. The spark was discharged directly to the downstream
edge of one swirl can.

Instrumentation

The combustor instrumentation stations are shown in figure 1. At
station 1, four total-pressure rakes, four static-pressure taps, and
four bare-wire chromel-alumel thermocouples measured the inlet total
pressure, inlet static pressure, and the inlet total temperature, respec-
tively. At station 2 a combined total-pressure and total-temperature
(platinum - 13 percent platinum-rhodium thermocouple) probe measured the
outlet total pressure and total temperature (ref. 4). Static pressure was
also measured at station 2. A single bare-wire chromel-alumel thermo-
couple was installed in the fuel manifold to measure the inlet fuel vapor
temperature for the vaporized JP-4 fuel tests.

Combustor Elements

The operation of a swirl-can combustor element is schematically shown
in figure 3. Vaporized propane or JP-4 fuel was injected from a simple
orifice at sonic velocity tangential to the inner surface and normal to
the axis of the can. The tangential velocity of the fuel caused the fuel
to spiral downstream along the walls of the can and mix rapidly with the
air admitted through the inlet orifice plate. Combustion was initiated
and stabilized within the swirl can. V-gutters were attached to the can
exit to spread the flame and increase the contact area between the hot
burning gases and cold air which passes around the combustor element.

Combustors

Model 1. - The first swirl-can combustor tested is shown in figure 4.
This combustor consisted of five large and five small swirl cans. Each
combustor element has V-gutters attached to the exit to act as flame
spreaders. Fuel was injected into each element from a single orifice in
the fuel tube.

The over-all combustion length for this combustor was 13.5 inches,
measured from the upstream face of the combustor elements to the second
instrumentation position. This position corresponds roughly to the
centerline of the turbine.

Model 2. - Figure 5 shows the second type of swirl-can combustor
tested. Twenty small swirl cans were arranged in three rows. Each row

was provided with a fuel control valve so that the fuel could be adjusted
between rows to give an optimum turbine-inlet temperature profile. A fuel-
supply tube, which draws fuel from the external fuel manifold, runs through
the center of each swirl can in a row. This arrangement allowed use of
two injection orifices for each swirl can instead of one as in the previous
combustor. The combustion length for this combustor was 11.0 inches.

JP-4 Fuel Vaporizer

Figure 6 shows the heat exchanger used to vaporize the JP-4 fuel.
It consisted of 9 feet of partially flattened 1/2-inch-diameter tubing,
and was positioned in the duct downstream of the second instrumentation
plane. The vaporized JP-4 fuel was passed through insulated tubes outside
the combustor housing to the external fuel manifold. The heat exchanger
was used solely as a source of vapor fuel and was not intended to repre-
sent a proposed design for use in an engine.

Table I shows the operating conditions over which the performance of
the two experimental combustors was tested.

RESULTS AND DISCUSSION

A summary of the results obtained in this investigation is presented
in table II.

Combustion Efficiency

Propane fuel. - Figure 7 compares the operation of models 1 and 2 at
the same test conditions (combustor-inlet total pressure, 14.7 in. Hg abs;
reference velocity, 75 ft/sec) with propane as the fuel. The combustion
efficiency of model 1 is 87 to 90 percent over a wide range of fuel-air
ratios, while that of model 2 is somewhat lower, ranging from 80 to 85
percent over a relatively narrow range of fuel-air ratios. Unstable op-
eration and intermittent blowout of some of the elements of model 2 were
often observed. Model 1 however, performed well at all fuel-air ratios
with no blowout observed.

The combustion efficiency of model 2 at test conditions simulating
supersonic flight at high altitudes is shown in figure 8(a). Here, combus-
tion efficiency was 97 to 100 percent at the higher pressure conditions
of 25 and 30 inches of mercury absolute (reference velocity, 120 ft/sec;
inlet-air total temperature, 1160° R) and decreased for the lower pressure
test conditions only at fairly high fuel-air ratios. However, it is
doubtful that such a combustor in a supersonic engine during full-throttle
cruise would ever experience combustor pressures much below 30 inches of
mercury absolute.

Figure 8(b) shows combustion efficiency of model 2 operating at
the same simulated supersonic flight test conditions as in figure 8(a),
except that the combustor reference velocity was increased to 180 feet
per second. This combustion efficiency is somewhat lower than that shown
previously in figure 8(a). Furthermore, combustor blowout was experienced
at a combustor inlet total pressure of 17 inches of mercury absolute.
The combustion efficiency of this short configuration may possibly be
limited by the very high reference velocity.

The performances of models 1 and 2 are compared with those of a
present-day turbojet combustor and an NACA experimental combustor (ref. 5)
in figure 9. Combustion efficiency is plotted against the combustion pa-
rameter V_{ref}/P_iT_i. Both models 1 and 2 do not equal the performance of
the longer length conventional combustor at high values of the combustion
parameter because they do not perform well at low combustor pressures.
However, at pressures above 1 atmosphere, the short swirl-can combustors
give substantially 100 percent combustion efficiency, as noted in figure
8(a). Thus, these models are quite satisfactory for most future super-
sonic aircraft, since combustor pressures below 1 atmosphere will probably
not be encountered. It should also be noted that the work reported
herein is preliminary in nature, and further work may result in considerable
improvement in combustor efficiency.

JP-4 fuel. - A plot of combustion efficiency against fuel-air ratio,
comparing the propane and JP-4 fuel performance of model 1, is presented
in figure 10. Combustion efficiency varied between 77 and 80 percent
at a combustor-inlet total pressure of 14.7 inches of mercury absolute
and a reference velocity of 75 feet per second. Combustion efficiency
with JP-4 fuel is lower than that achieved with propane fuel at all
fuel-air ratios. The loss in efficiency at low fuel-air ratios was pos-
sibly caused by the JP-4 fuel being only partly vaporized (about 75 to 90
percent) at the low fuel flows. Further, the swirl-can combustor elements
may not have been correctly designed for optimum combustion of JP-4 fuel.

Pressure Loss

The total-pressure loss in percent of the inlet total pressure for
models 1 and 2 is plotted in figure 11 against the combustor total-
temperature ratio. At similar test conditions, no significant differences
between the pressure losses for models 1 and 2 were observed. At a ref-
erence velocity of 75 feet per second, the total-pressure loss is about
1 percent; this is a considerable reduction over the 5 percent pressure
loss for conventional combustors operating at similar conditions. At a
reference velocity of 180 feet per second, the total-pressure loss for
model 2 ranged from 5 to 6 percent.

Temperature Profiles

Figure 12 shows a comparison between the average radial turbine-inlet temperature profiles for models 1 and 2 at similar test conditions. The profile obtained with model 1 is unsatisfactory and could not be substantially improved, separate fuel flow control to each row of combustor elements being unavailable. The profile obtained with model 2 shows the degree of control afforded when separate fuel controls are provided to each row of combustor elements. This use of separate fuel-flow controls to each row of combustor elements simplifies the problem of correctly determining the size of the fuel orifices to be used on each row of swirl cans.

Durability

At no time during the experimental program was any failure of the combustors or their fuel tubes due to heat distortion or pressure effects noted. Instead, all the metal parts were kept quite cool by the fuel and only at very high fuel-air ratios and high inlet-air temperatures was any heating of the combustor elements observed. As has been stated, this heating was so minor that no damage was incurred.

Combustor Length

The over-all combustion lengths of models 1 and 2 were 13.5 and 11.0 inches, respectively. This length is defined as the distance from the upstream face of the combustor elements to the instrumentation position. The following table shows a comparison of lengths among several conventional turbojet combustors and the two experimental ones:

Type	Length, in.
Conventional combustor:	
A	36.5
B	22.5
C	24.5
D	26.0
E	37.0
F	22.0
Short combustors:	
Model 1	13.5
Model 2	11.0

It is obvious that a considerable reduction in combustion length is possible by using the combustor-element design approach. Even when the

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shortest conventional combustors are used, the combustor length can still be reduced one-half by using a swirl-can combustor.

SUMMARY OF RESULTS

The following results were obtained in the investigation of two short (11- and 13.5-in. over-all combustor length) turbojet combustors consisting of arrays of swirl-can combustor elements burning propane or prevaporized JP-4 fuel:

1. Combustion efficiencies from 80 to 90 percent were obtained at a simulated altitude of 70,000 feet and simulated flight Mach number of 0.9 (combustor-inlet total pressure, 14.7 in. Hg abs and reference velocity, 75 ft/sec) with both combustor configurations using propane fuel. Combustion efficiencies from 77 to 80 percent were obtained with one combustor configuration operating at the same test conditions using vaporized JP-4 fuel.

2. A combustion efficiency of 97 percent was obtained with propane fuel at an inlet total pressure of 25.0 inches of mercury absolute, reference velocity of 120 feet per second, and an inlet-air total temperature of 1160° R. This test condition simulated an altitude of 83,000 feet, and a flight Mach number of 2.85 for a turbojet engine having a sea-level static compressor total-pressure ratio of 2.2.

3. By proportioning the fuel flow between the manifolded rows of swirl-can combustor elements, control of the combustor-outlet temperature profile was demonstrated.

4. Combustor total-pressure losses ranged from 0.75 percent of the combustor-inlet total temperature at a reference velocity of 75 feet per second and isothermal conditions to 5.5 percent at a reference velocity of 180 feet per second and a total-temperature ratio of 1.8.

CONCLUDING REMARKS

The two swirl-can combustors investigated herein did not give high combustion efficiencies at some of the low combustor pressures encountered in subsonic flight. However, over the range of combustor pressures expected in most future supersonic flight aircraft, these combustors provide nearly 100 percent efficiency. Also, they have an over-all length less than one-half that of conventional turbojet combustors, and give combustor pressure losses less than one-third those of most conventional combustors.

Swirl-can combustors therefore appear to offer marked advantages over more conventional combustor designs for future turbojet engines.

Lewis Flight Propulsion Laboratory
    National Advisory Committee for Aeronautics
        Cleveland, Ohio, October 8, 1957

REFERENCES

1. Zettle, Eugene V., Norgren, Carl T., and Mark, Herman: Combustion Performance of Two Experimental Turbojet Annular Combustors at Conditions Simulating High-Altitude Supersonic Flight. NACA RM E54A15, 1954.

2. Zettle, Eugene V., and Friedman, Robert: Performance of Experimental Channeled-Wall Annular Turbojet Combustor at Conditions Simulating High-Altitude Supersonic Flight. I - U-Shaped Channel Walls for Secondary-Air Entry. NACA RM E54L21a, 1955.

3. McCafferty, Richard J., Wear, Jerrold D., and Cook, William P.: Performance at High Temperatures and Pressures of an Annular Turbojet Combustor Having Articulated Liner Walls. NACA RM E57B26, 1957.

4. Friedman, Robert, and Carlson, Edward R.: A Polar-Coordinate Survey Method for Determining Jet-Engine Combustion-Chamber Performance. NACA TN 3566, 1955.

5. Norgren, Carl T.: Performance at Simulated High Altitudes of a Prevaporizing Annular Turbojet Combustor Having Low Pressure Loss. NACA RM E56I14, 1956.

TABLE I. - COMBUSTOR OPERATING CONDITIONS

Inlet total pressure, in. Hg abs	Air-flow rate, lb/sec	Inlet total temperature, °R	Reference velocity, ft/sec (a)	Simulated altitude, ft	Simulated flight Mach number	Fuel	Combustor model
14.7	1.28	810	75	70,000	0.9[b]	Propane	1 and 2
14.7	1.38		81	70,000	.9	JP-4	1
21.3	2.56	↓	100	60,000	.9	JP-4	1
15.0	1.51	1160	120	94,000	2.85[c]	Propane	2
20.0	2.01		↓	88,000	2.85		
25.0	2.51			83,000			
30.0	3.01		↓	79,000			
20.0	3.01		180	88,000			
25.0	3.76	↓	180	83,000	↓	↓	↓

[a]Based on combustor reference area of 0.726 sq ft and inlet total conditions.

[b]For an engine having a sea-level static compressor total-pressure ratio of 6.8.

[c]For an engine having a sea-level static compressor total-pressure ratio of 2.2. Reference velocities for simulated supersonic flight conditions do not represent true engine reference velocity, but were intended only for use as rough approximations.

TABLE II. - EXPERIMENTAL DATA

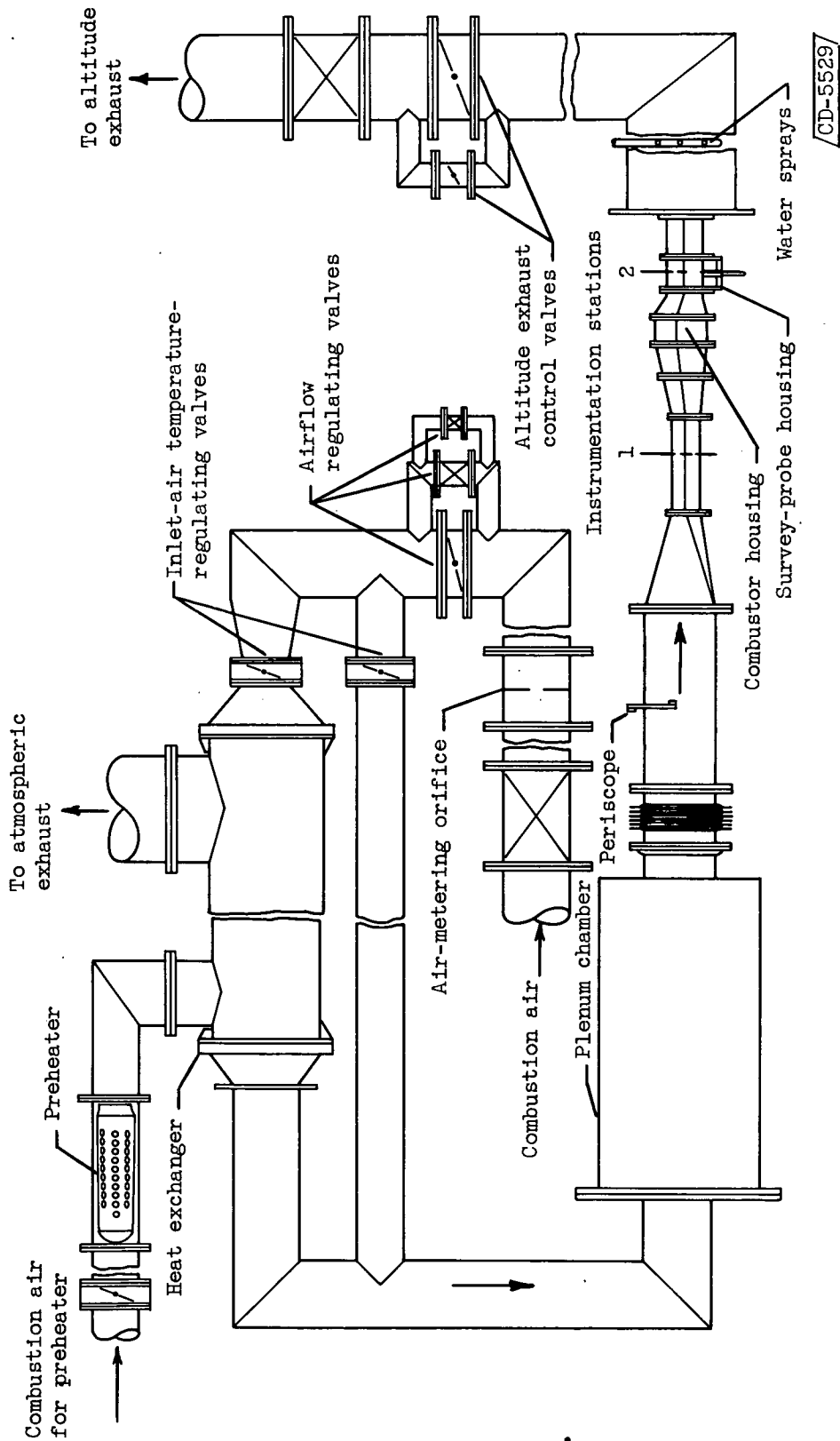| Run	Combustor inlet total pressure, in. Hg abs	Combustor inlet total temperature, °R	Air-flow rate, lb/sec	Combustor reference velocity, ft/sec	Fuel-flow rate, lb/hr	Fuel-air ratio	Mean combustor outlet total temperature, °R	Mean total temperature rise, °R	Combustion efficiency,	Fuel inlet temperature, °F	Total pressure loss, $\Delta P/P_1$
Propane fuel; model 1										
1	14.7	810	1.280	73.0	57.32	0.01240	1624	814	87.9	~80	0.96
2	14.7	810	1.279	72.9	41.26	.00896	1406	596	86.6		.99
3	14.7	810	1.280	73.0	68.87	.0149	1801	991	90.6		1.10
4	14.7	810	1.275	72.7	92.45	.0201	2088	1278	87.2		1.30
Propane fuel; model 2										
5	15.0	1160	1.558	124.7	83.80	0.01490	2101	941	90.6	~80	2.40
6			1.562	125.0	55.73	.00991	1825	665	93.9		2.20
7			1.520	121.7	99.64	.01821	2100	940	75.2		2.50
8	20.0	1160	2.065	124.0	89.8	0.01208	1975	815	95.4	~80	
9			2.065	124.0	125.1	.01683	2265	1105	95.5		
10			2.060	123.7	65.2	.00880	1765	605	95.4		
11			2.080	124.9	87.83	.01170	1942	782	94.4		2.17
12			2.080	124.9	132.68	.01770	2271	1111	91.5		2.61
13			2.071	124.3	123.89	.01662	2144	984	85.8		2.54
14			2.071	124.3	140.87	.01890	2158	998	77.2		2.65
15	25.0	1160	2.570	123.4	100.07	0.01090	1919	759	97.7	~80	2.06
16			2.570	123.4	125.46	.01360	2085	925	96.7		2.38
17			2.762	123.0	144.73	.01570	2207	1047	96.2		2.56
18			2.762	123.0	151.36	.01640	2206	1046	92.0		2.38
19	30.0	1160	3.105	124.3	108.78	0.00973	1878	718	103.1	~80	2.00
20			3.105	124.3	134.99	.01200	2029	869	102.5		2.30
21			3.086	123.5	147.00	.01320	2104	944	101.9		2.30
22			3.095	123.9	169.22	.01519	2207	1047	99.3		2.48
23			3.095	123.9	199.27	.01789	2351	1191	97.2		2.57
24	20.0	1160	3.096	185.9	95.08	0.00853	1706	546	88.2	~80	5.11
25	20.0		3.095	185.8	121.22	.01088	1841	681	87.6		5.40
26	25.0	1160	3.919	188.2	145.83	0.01034	1840	680	92.2	~80	5.65
27	25.0		3.919	188.2	186.94	.01325	1943	783	83.7		5.91
28	25.0		3.919	188.2	216.31	.01533	2032	872	81.7		5.97
29	14.7	810	1.240	70.7	71.4	0.01600	1803	993	85.0	~80	1.00
30			1.277	72.8	50.4	.01100	1481	671	80.8		1.00
31			1.264	72.1	58.6	.01290	1594	884	81.3		1.00
32			1.269	72.4	81.5	.01780	1848	1038	80.3		1.00
JP-4 fuel, vaporized; model 1										
33	21.3	810	2.535	99.8	60.9	0.00667	1181	371	74.2	387	1.69
34					85.5	.00937	1331	521	75.4	407	1.76
35					104.8	.01148	1473	669	80.4	435	1.90
36					124.7	.01367	1626	816	83.5	470	1.97
37			2.540	100.0	150.2	.01643	1789	979	84.6	505	2.07
38			2.535	99.8	177.1	.01941	1963	1153	85.4	560	2.24
39			2.505	98.6	209.0	.02318	2161	1351	85.6	570	2.48
40	14.7	810	1.425	81.3	47.2	.00920	1337	527	77.9	480	1.25
41					58.4	.01140	1472	662	79.8	515	1.45
42					63.4	.01236	1499	689	76.3	510	1.35
43					70.6	.01376	1599	789	79.8	515	1.35

Figure 1. - Installation of experimental one-quarter-sector annular housing for investigation of short turbojet combustor.
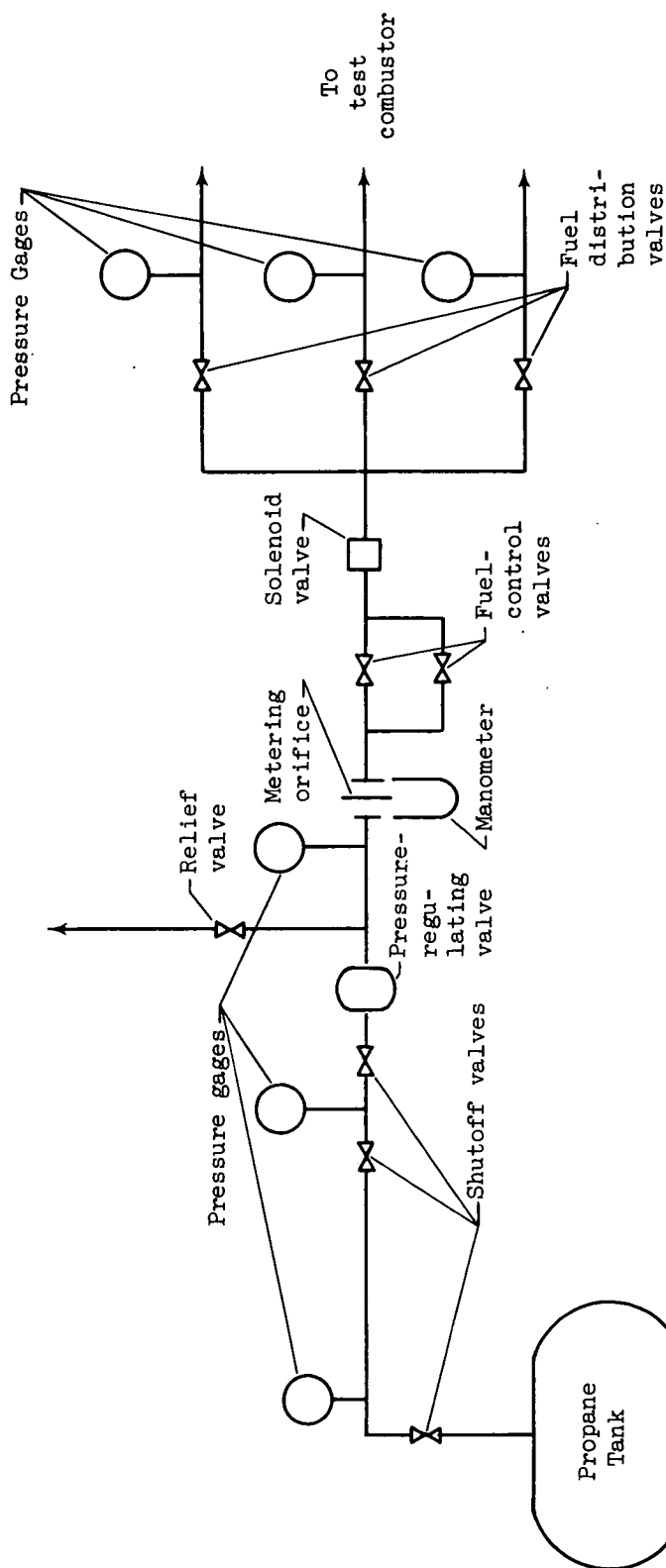
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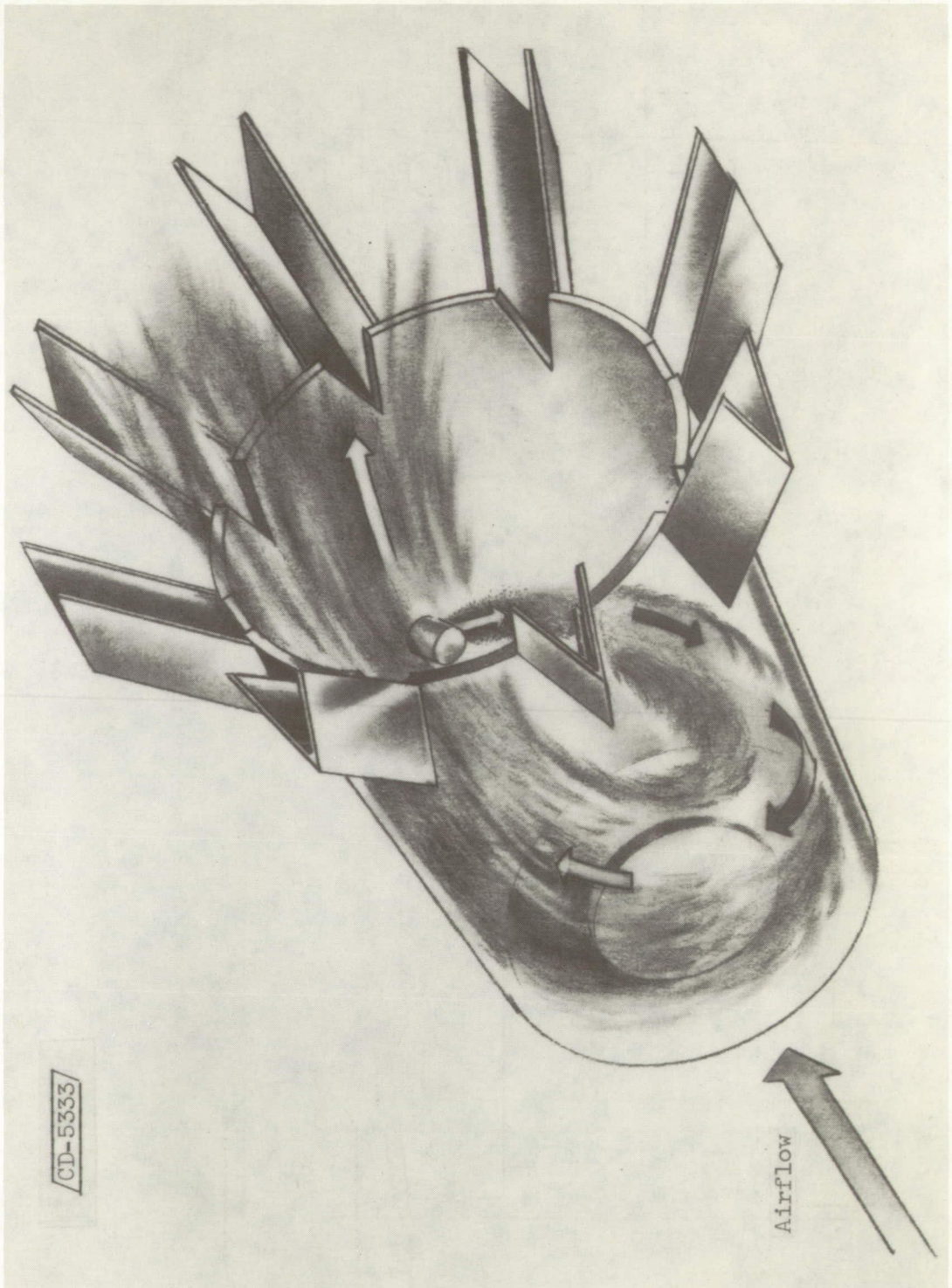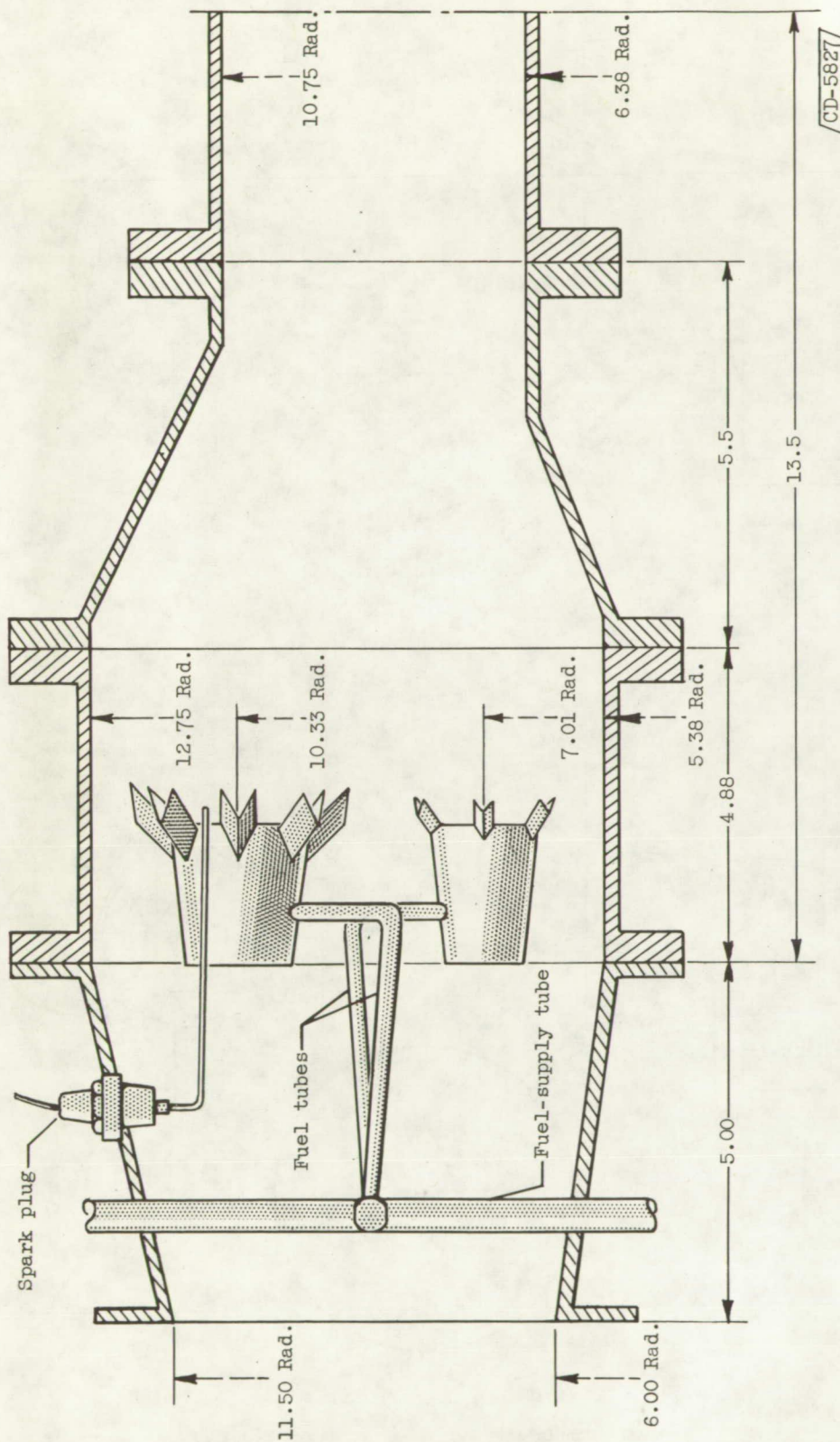

Figure 2. - Schematic diagram of propane fuel system.

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Airflow

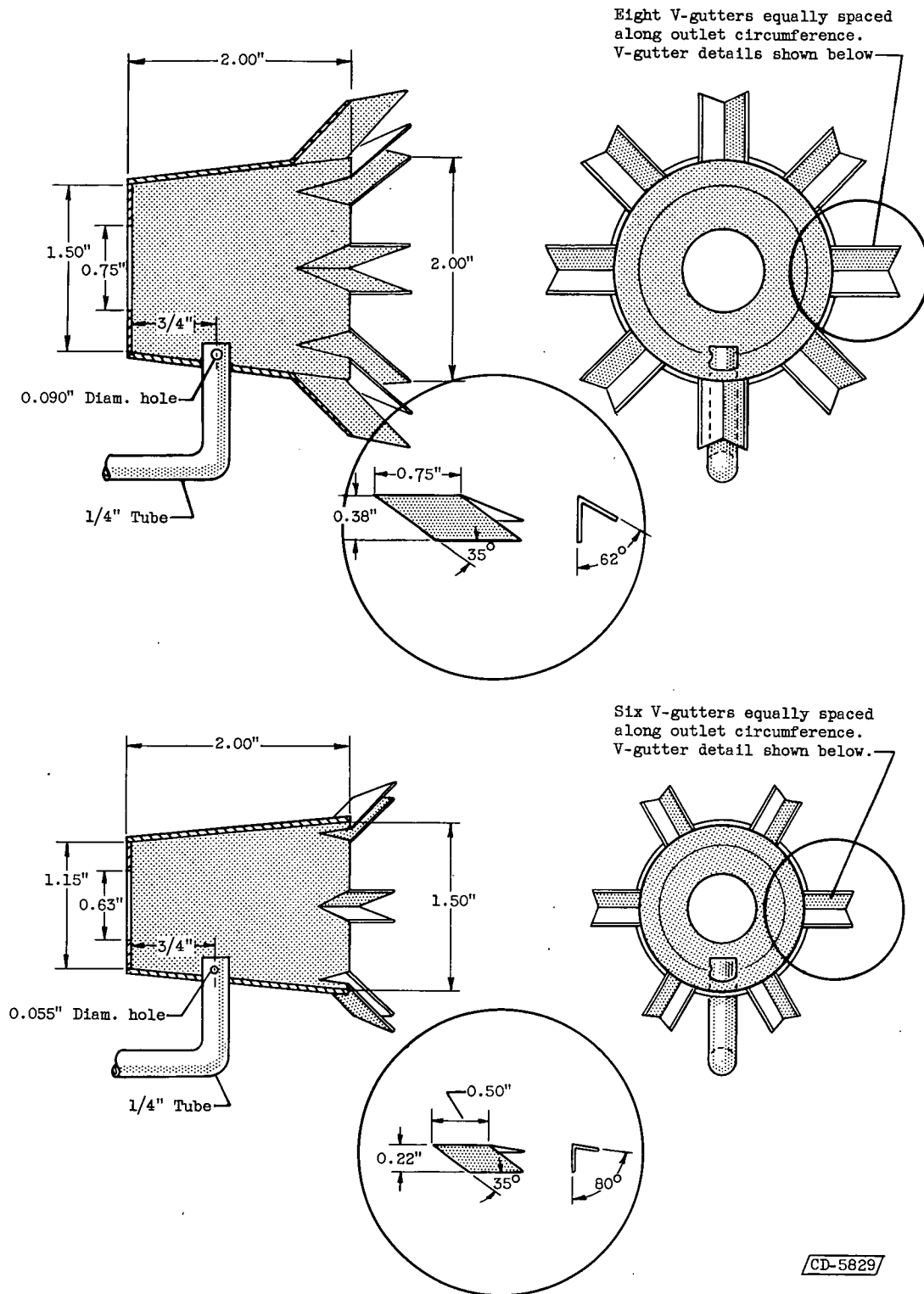Figure 3. - Pictorial representation of operation of swirl-can combustor element.

(a) Cross-section model mounted in one-quarter sector annular housing. (All dimensions in inches.)
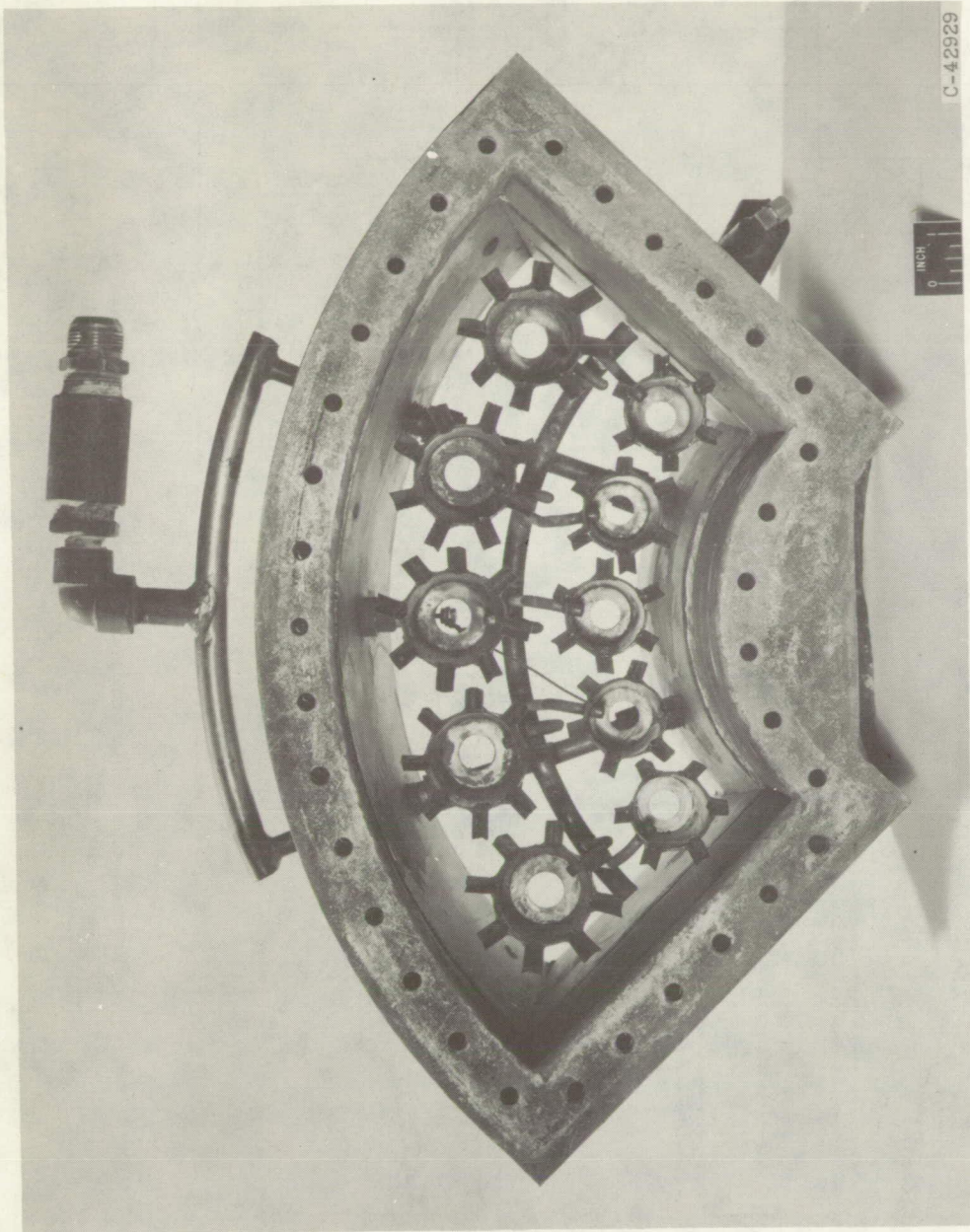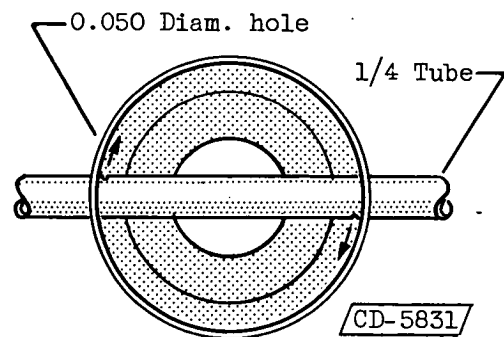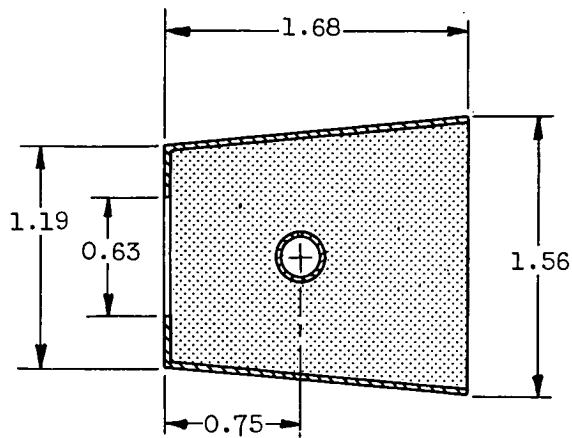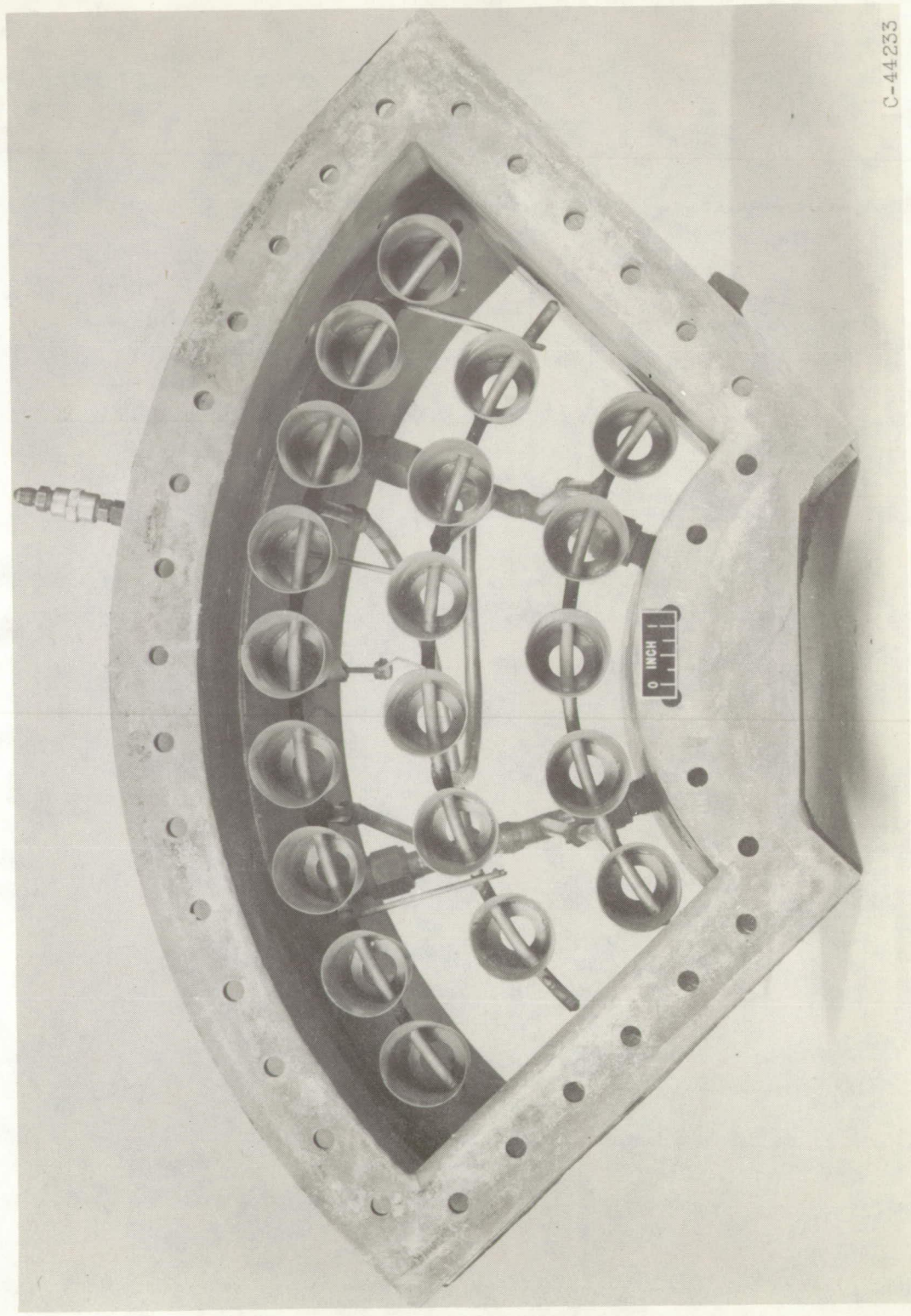
Figure 4. - Swirl-can combustor, model 1.

Eight V-gutters equally spaced
along outlet circumference.
V-gutter details shown below

2.00"

1.50"
0.75"
3/4"
2.00"

0.090" Diam. hole

1/4" Tube

0.75"
0.38"
35°
62°

Six V-gutters equally spaced
along outlet circumference.
V-gutter detail shown below.

2.00"

1.15"
0.63"
3/4"
1.50"

0.055" Diam. hole

1/4" Tube

0.50"
0.22"
35°
80°

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(b) Details of swirl can.

Figure 4. - Continued. Swirl-can combustor, model 1.

(c) Model mounted in one-quarter sector annular housing.

Figure 4. - Concluded. Swirl-can combustor, model 1.

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10.75 Rad.

6.38 Rad.

11.28 Rad.

9.28 Rad.

6.67 Rad.

12.75 Rad.

Fuel tubes

Fuel-supply tubes

Spark plug

5.50

11.0

4.87

5.38 Rad.

5.0

11.05 Rad.

6.00 Rad.

(a) Cross-section mounted in one-quarter-sector annular housing.
(All dimensions in inches.)

Figure 5. - Swirl-can combustor, model 2.

(b) Details of swirl cans. (All dimensions in inches.)

Figure 5. - Continued. Swirl-can combustor, model 2.

(c) Model mounted in one-quarter sector annular housing.

Figure 5. - Concluded. Swirl-can combustor, model 2.

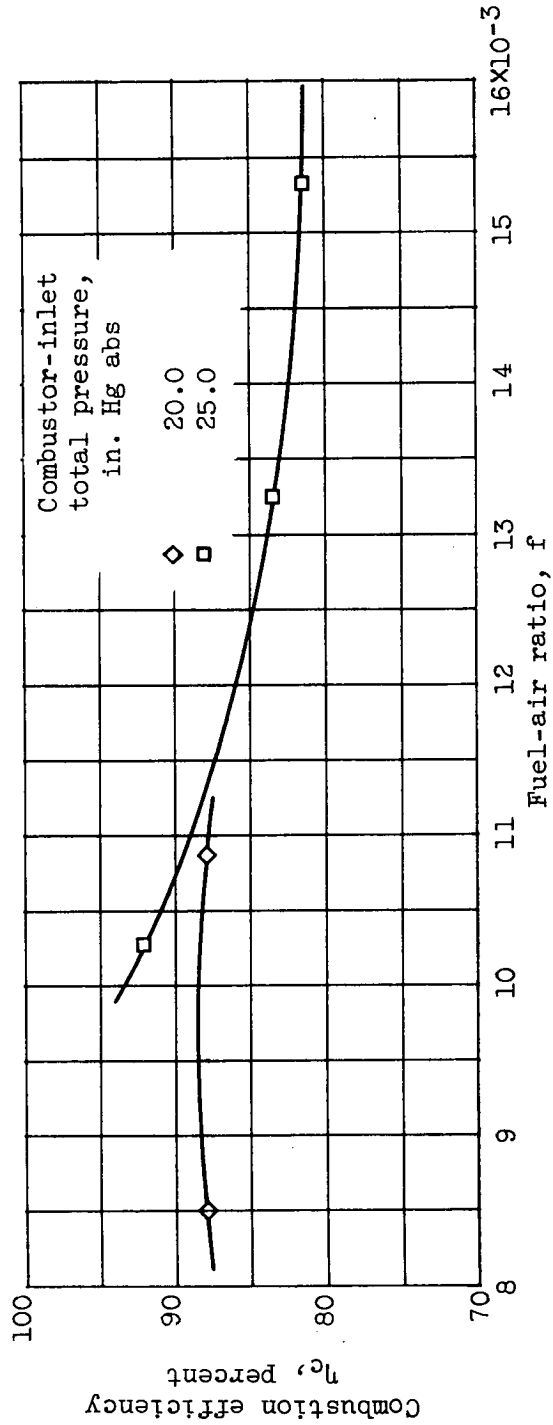Figure 6. - JP-4 fuel vaporizer.

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Figure 7. - Comparison of efficiency of models 1 and 2 using propane fuel. Combustor-inlet total pressure, 14.7 inches of mercury absolute; inlet-air total temperature, 810° R; combustor reference velocity, 75 feet per second.

(a) Combustor reference velocity, 120 feet per second. Inlet-air total temperature, 1160° R.

Figure 8. - Combustion efficiency of model 2 using propane fuel.

(b) Combustor reference velocity, 180 feet per second.

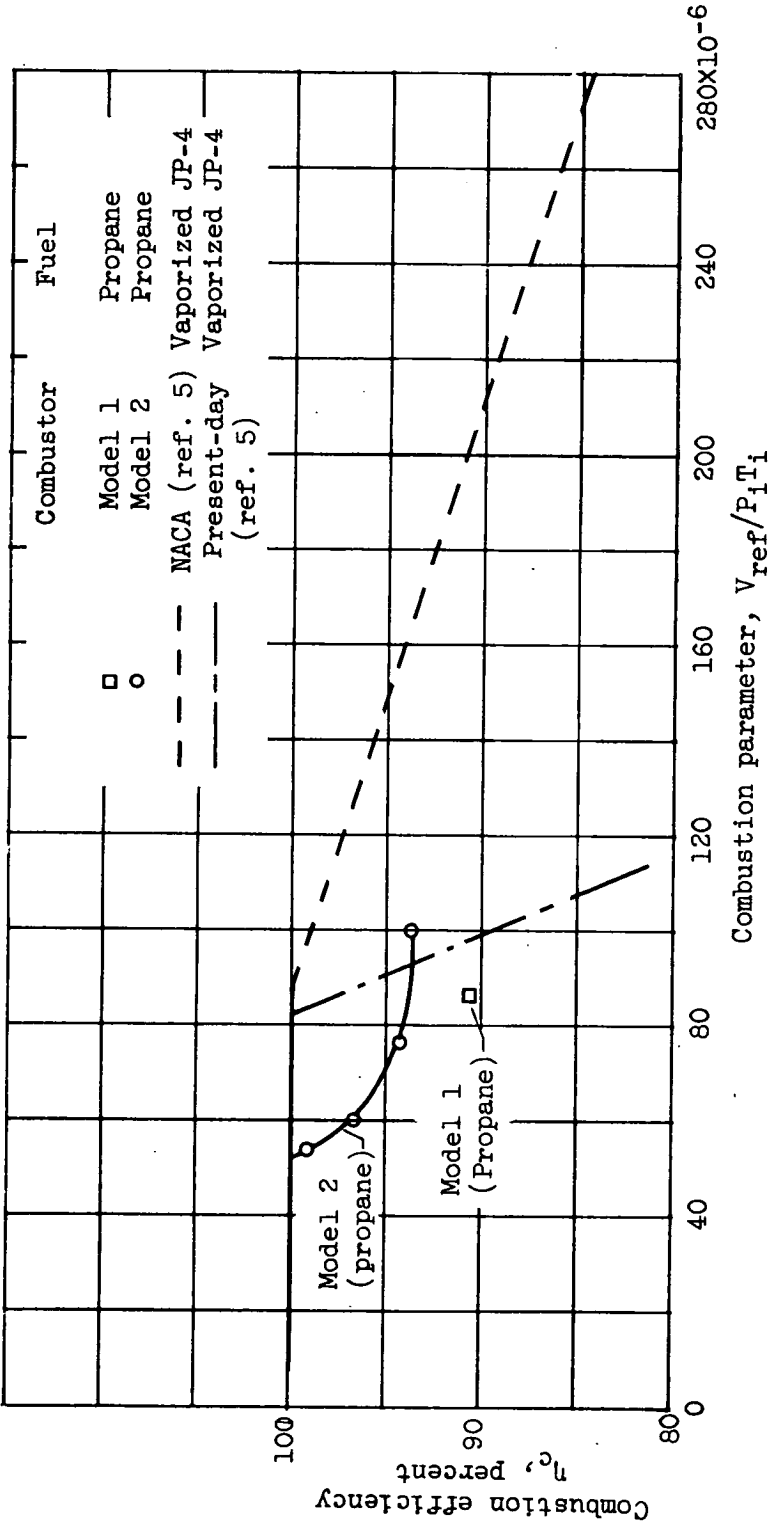Figure 8. - Concluded. Combustion efficiency of model 2 using propane fuel. Inlet-air total temperature, 1160° R.

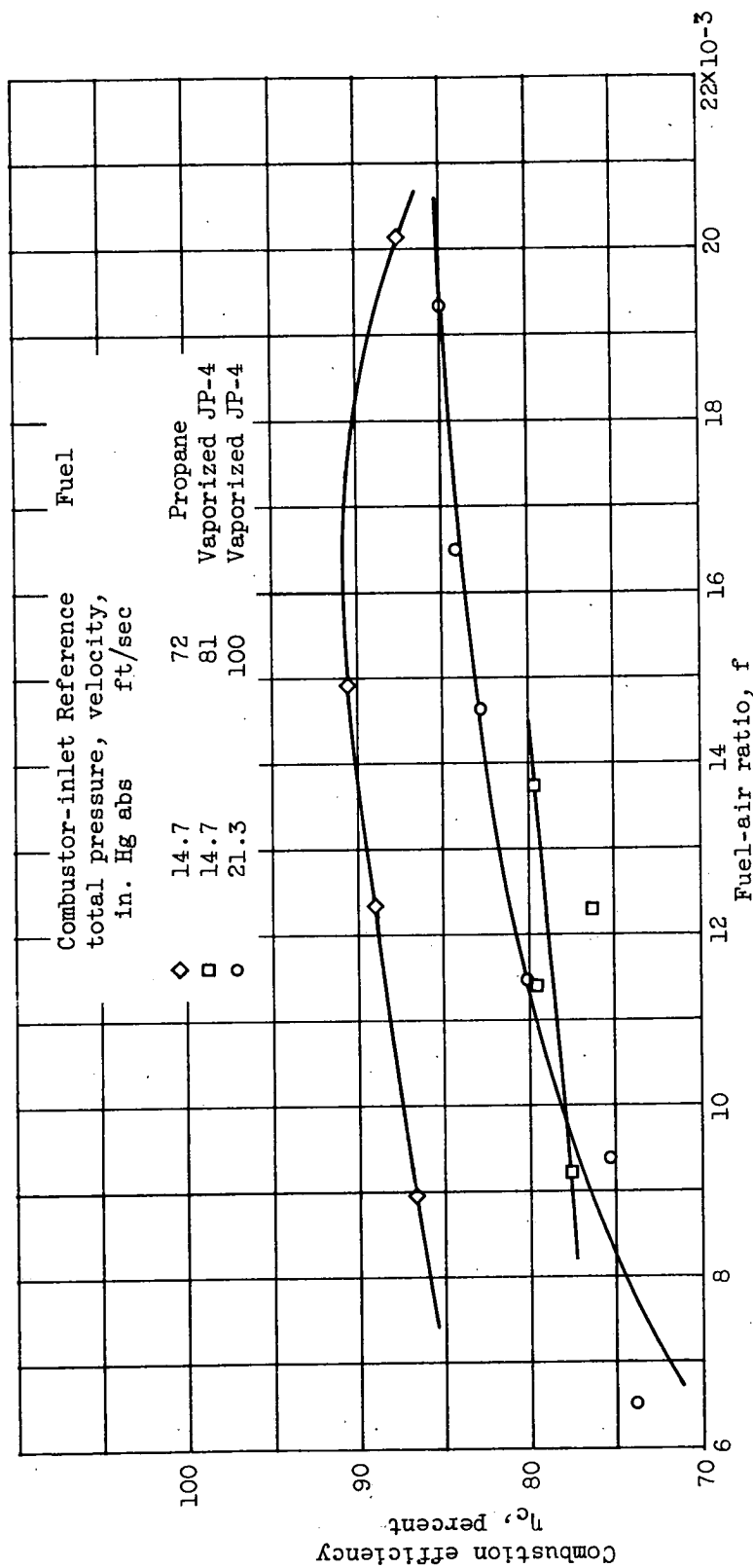Figure 9. - Variation of combustion efficiency and combustion parameter.

Figure 10. - Combustion efficiency for model 1 using propane and vaporized JP-4 fuel. Inlet-air total temperature, 810° F.

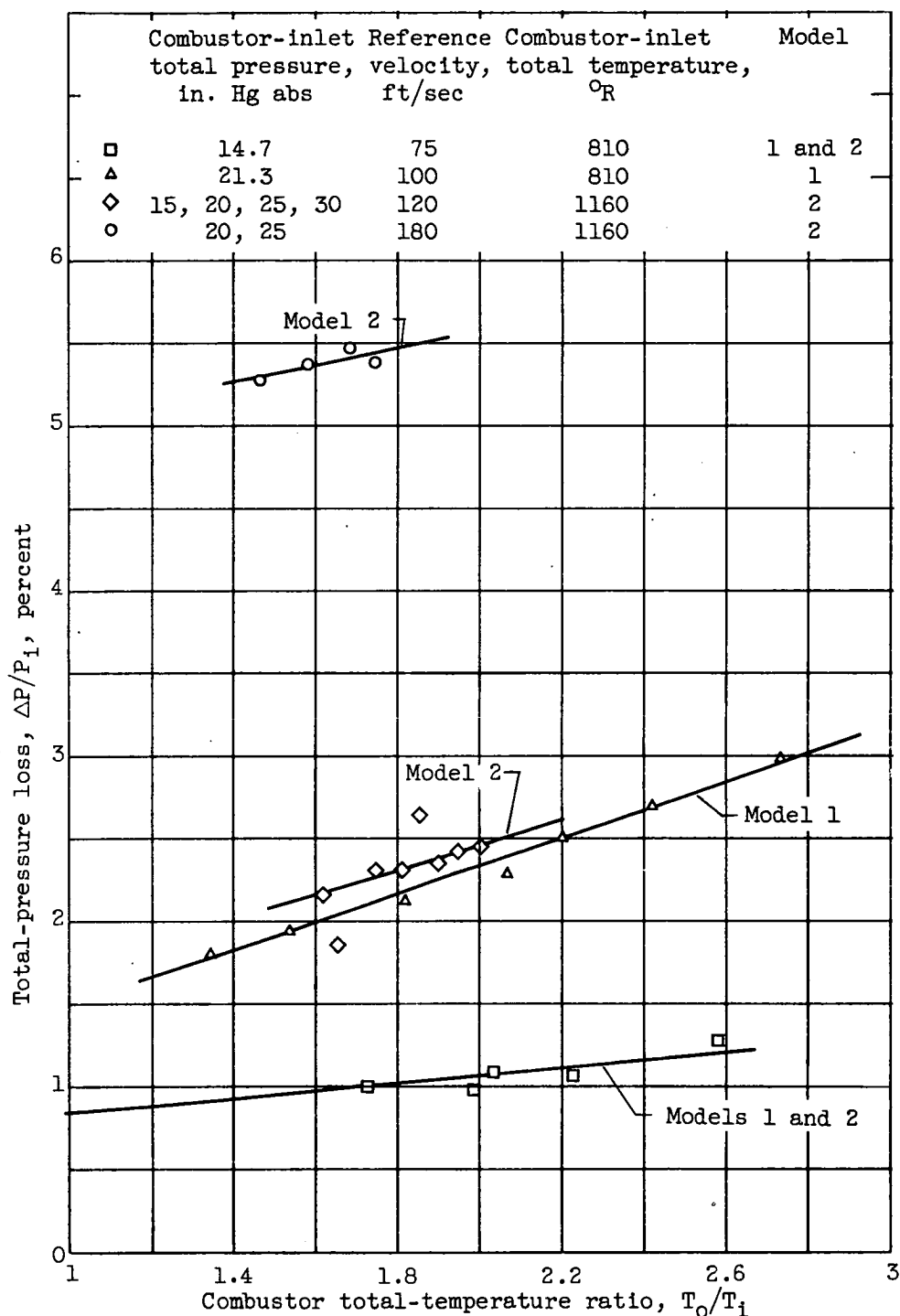| Combustor-inlet total pressure, in. Hg abs	Reference velocity, ft/sec	Combustor-inlet total temperature, °R	Model
□ 14.7	75	810	1 and 2
△ 21.3	100	810	1
◇ 15, 20, 25, 30	120	1160	2
○ 20, 25	180	1160	2

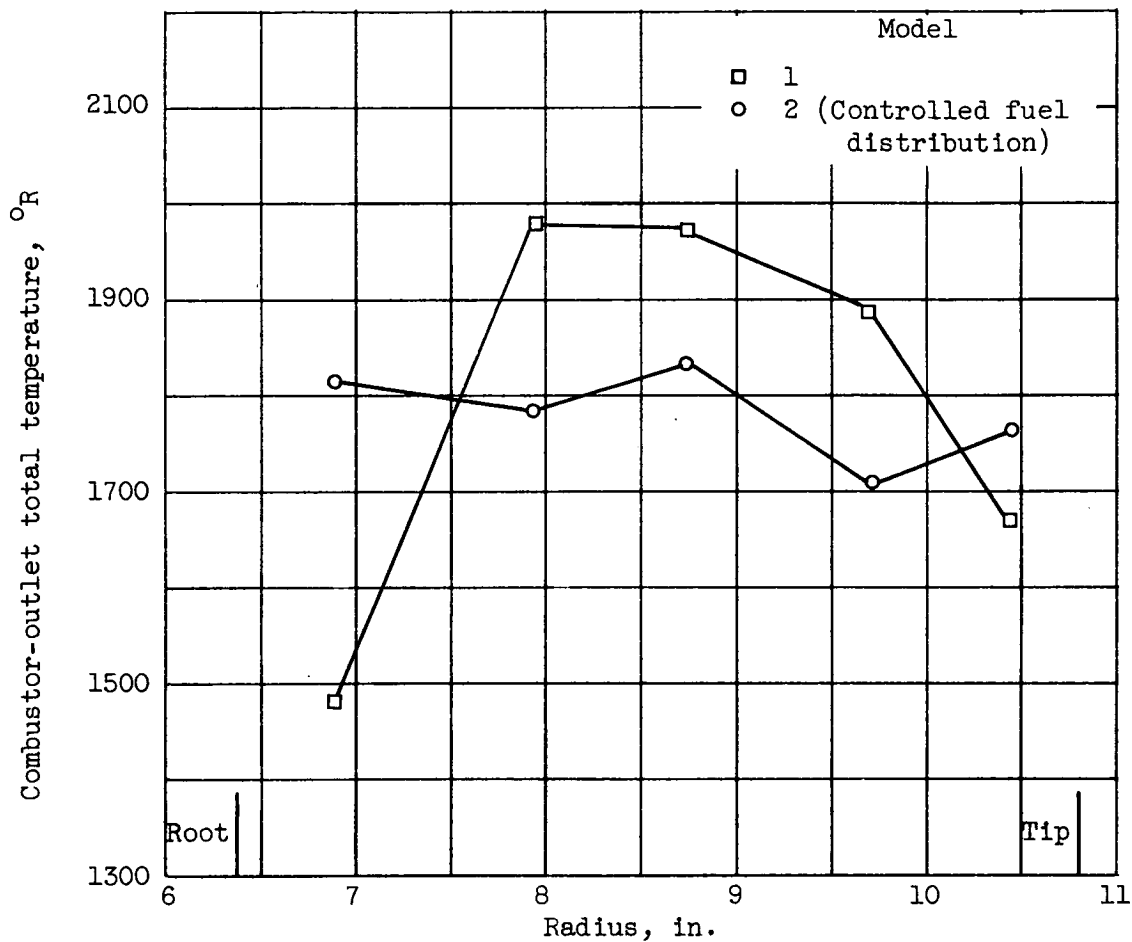Figure 11. - Variation of total-pressure loss with combustor total-temperature ratio for models 1 and 2.

Figure 12. - Comparison of average radial temperature profiles for models 1 and 2. Combustor-inlet total pressure, 14.7 in. Hg abs; reference velocity, 75 ft/sec; inlet-air total temperature, 810° R. Average outlet total temperature: model 1, 1801° R; model 2, 1780° R.